A Tall Ship and a Star to Steer Her By

Completed Technology Project (2015 - 2016)

Project Introduction

The Differential Deployable Autonomous Radio Navigation (_DARN) brings astronomical radio observations of quasars, masers and pulsars into play as a means to autonomously guide spacecraft among the planets, and even to the stars. The roadmap leads to a demonstration mission and utilization on deep space missions large and small. Phase 1 will produce a preliminary catalog of reference maser sources, a system analysis, and conceptual design of a demonstration mission.

Anticipated Benefits

With spacecraft components and kits\xd3 becoming commodities available even to small university groups, advances in low thrust propulsion [11] and optical communication [12] have brought closer the day when small, inexpensive probes will ply the interplanetary spaceways. Recent conferences and workshops have been dedicated to the prospect of deep space CubeSats alone [13]. At present, however, the infrastructure for deep space navigation is an expensive bottleneck to ubiquitous access to deep space. While star trackers provide attitude and crude position information, and inertial guidance units provide short-term velocity and position information, ultimately deep space navigation depends on two-way Doppler and ranging measurements from Earth. A giant leap in the accessibility of deep space exploration will occur when near-autonomous navigation becomes a reality. Not only does this break the tether to Earth, but it also enables exploration beyond the line of sight to Earth behind planets, the sun, or even in interstellar space. The immediate benefit of the proposed study is an understanding of how unusual astronomical objects can be exploited for autonomous navigation. This information is a reasonable outcome of the proposed intensive observational campaign, and will explicitly determine whether further development of the concept is warranted. Promising results of this study bring nearer the day when student groups and other small organizations typical of today's CubeSat community will be able to ply the entire solar system (or, in fact, beyond) as readily as they explore orbital space today. This will lead not only to new discovery, but to engagement of the public and academic community on an entirely new scale.

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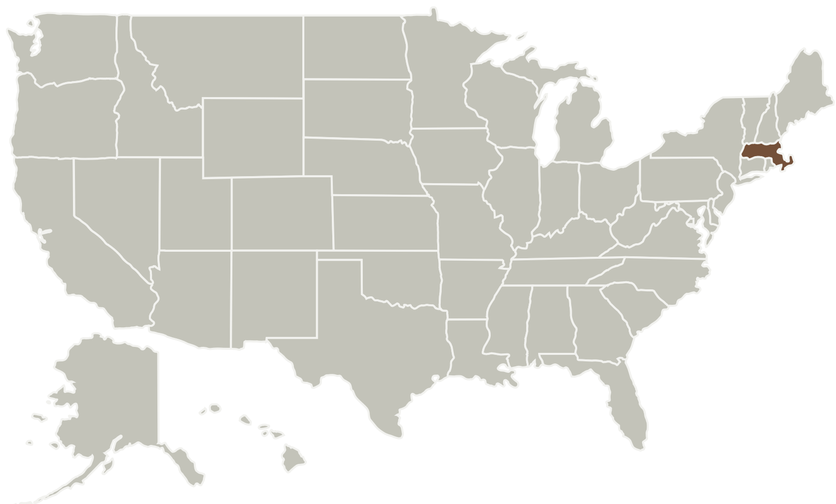
Table of Contents

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
Massachusetts Institute of Technology(MIT)	Lead Organization	Academia	Cambridge, Massachusetts
Stellar Exploration, Inc.	Supporting Organization	Industry	San Luis Obispo, California

Primary U.S. Work Locations
Massachusetts

Project Transitions

July 2015: Project Start

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

Massachusetts Institute of Technology (MIT)

Responsible Program:

NASA Innovative Advanced Concepts

Project Management

Program Director:

Jason E Derleth

Program Manager:

Eric A Eberly

Principal Investigator:

Michael H Hecht

Co-Investigators:

Frank D Lind
Tomas Svitek
Vincent L Fish

June 2016: Closed out

Closeout Summary: The vision: Sailing ships once navigated by the fixed stars and a nautical chronometer. Untethered from the terrestrial reference frame, future spacecraft will require more than a star chart to accomplish the same feat; instead, they may exploit the peculiar time and frequency structure of light from those distant stars to autonomously or semiautonomously determine their position and velocity in the celestial reference frame. 1.1 Broad Objectives: Two visionary innovations were proposed to allow spacecraft to assume the burden of navigation. The first extends the International Celestial Reference Frame (ICRF) to include not only orientation references (quasars), but also time (pulsars) and frequency (maser) references that allow position and velocity to be determined relative to the terrestrial reference frame (TRF) or planetary reference frames (PRFs). The second provides spacecraft with a direct means to determine their own position relative to the ICRF. 1.2 Proposed approach: The inspiration for the Tall Ship proposal was the progress being made towards using time-of arrival (TOA) and Doppler shift X-ray signatures of millisecond pulsars in support of autonomous spacecraft navigation. This technique, sometimes dubbed xNAV, will be tested at a proof-of concept level as part of the upcoming NICER/SExTANT experiment on the International Space Station (Arzoumanian et al. 2014). While xNAV is promising, the X-ray signal from pulsars is intrinsically weak, the detection instrumentation is cumbersome and single-purpose, and the overall resource burden on small spacecraft is likely to be large even after projecting the technology forward in time. In that respect, analogous techniques implemented using radio methods in the microwave bands (what might be called RNAV) may be preferable. The signal-to-noise ratio of the sources is higher in the microwave, the technology better lends itself to miniaturization, and large radio antennas and receivers are more synergistic with other spacecraft subsystems in the sense that they can contribute towards communication, and can share collecting area with a solar power system. Electronic beamforming technology will potentially reduce most of the pointing burden on the spacecraft as it matures, and (as described here), bright and ubiquitous astronomical masers, which provide frequency references for Doppler measurements, may complement or even replace the rare and difficult-to-detect pulsars as catalogue sources. The Tall Ship team therefore proposed to observationally determine, first, whether well-known astronomical masers are sufficiently stable on short time scales to constitute an ICRF sub-catalog that can be used for spacecraft navigation. Second, we proposed to assess the scope of spacecraft resources that would be required to exploit such a catalog, including antenna area, deployment mechanisms, power, and computational capability. Finally, we proposed to explore deployment of even larger antennas from small spacecraft that would be able to utilize both pulsars and masers for navigation. 1.3 Findings By way of overall summary, the prospect of autonomous navigation with astronomical masers proved less inviting in light of the Phase I research findings, but the prospect of using radio pulsars was significantly improved. The difference in the degree of difficulty is nowhere near as great as initially expected, and the navigational value of radio pulsar signals is found to be significantly greater. Moreover, a straightforward and inexpensive path to flight validation was identified. 1.3.1 RNAV with masers Despite the need for an extra integral to extract position information from Doppler shifts, we originally focused on astronomical masers because of the relative simplicity of detection, the ubiquity of bright sources, and the opportunity to use relatively small antennas to detect bright sources in the 3-30 mm (10-100 GHz) range. Initial estimates of signal strength suggested that 1 m2 would be adequate antenna area, a size nominally compatible with a CubeSat. Observations: Initial observations using the Haystack Observatory

Technology Maturity (TRL)

Start: **2**
Current: **3**
Estimated End: **3**

1 2 3 4 5 6 7 8 9

Applied Research | Development | Demo & Test

Technology Areas

Primary:

- TX04 Robotic Systems
  - └ TX04.1 Sensing and Perception
    - └ TX04.1.2 State Estimation

Target Destination

Foundational Knowledge

Project Website:

https://www.nasa.gov/directorates/spacetech/home/index.html